DONNERSBERGER

Re-Cementation Tests of Road Building Stone

Civil Engineering

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RE-CEMENTATION TESTS

OF

ROAD BUILDING STONE

BY

FRANK JOSEPH DONNERSBERGER

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

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C O L L E G E O F E N G I N E E R I N G

May 26, 1907

This is to certify that the following thesis prepared under the immediate direction of Mr. L. G. Parker, Instructor in Civil Engineering, by

FRANK JOSEPH DONNERSBERGER

entitled RE-CEMENTATION TESTS OF ROAD-BUILDING STONE

is accepted by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

Ira O. Baker.

Head of Department of Civil Engineering

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RE-CEMENTATION TESTS

OF

ROAD BUILDING STONE

INTRODUCTION

It has been found by experience that some stones make better road building materials than others. The old idea that any stone was good enough for road building had entirely disappeared until now we know of certain kinds of stone which are better adapted to road construction than others. Just what it is that causes this difference has been the subject of much discussion.

It is known that in order to keep a stone road in good condition, stone dust must be present which has the power of binding together the larger fragments of stone which make up the road bed. A test for determining this bonding quality or cementing value of stone dust was introduced in 1893 by Mr L. W. Page of the Massachusetts Highway Commission. On account of the variations in the process of making the cementation tests the results are quite variable.

It is therefore the purpose of this thesis to set forth the results of a series of tests made to investigate the causes of those variations and to suggest a standard test which will give more uniform results.

In the earlier tests a fine stone dust which would pass a one hundred mesh sieve was

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tempered with water and test pieces of various sizes and shapes were moulded. It was found that neither tension nor compression gave satisfactory results so the method finally adopted consisted in moulding test pieces in a cylindrical die under a definate pressure. These little cylindrical briquettes after being thoroughly dried were broken under the impact of a one kilogram hammer which fell a distance of one centimeter. The blows being repeated until failure occured.

In the earlier practice it was the custom to make a re-cementation test. The fragments from the broken briquettes were ground up, again mixed with water and immediately remoulded into briquettes. A very large number of tests showed that the recementing values were smaller than the origional cementing values. There were a few cases however where the reverse was true.

These inconsistent results led to the conclusion that the kneading of the dough and the time that the wet material is allowed to stand had something to do with the cementing values. Apparently the rock powders which have binding power, invariably undergo decomposition under the action of water, the decomposition products forming soft, more or less, adherent films on the surface of the particles. On drying out this adherent bond locks the particles together. After reaching this conclusion it was evident that a modification in the methods of making the briquettes was necessary. Since the bond is developed under the prolonged action of

water it was manifestly unfair to wet the stone dust and immediately mould into briquettes; also it was held that the amount of kneeding which is done on the wet mass will effect the softening of the particles and lower the strength of the bond. These variations were held to account for the inconsistency of the results in the cementation and recementation tests, so a new test was adopted which as now made us as follows:- The stone is broken up either with a hammer or a stone crusher and 1000 grams is placed in a ball mill and ground to a fine powder, five thousand revolutions being the standard number. This ball mill is a cast-iron shell mounted on a shaft with a revolution counter on the end of the shaft to indicate the number of revolutions, see Fig 1. Two steel balls weighing about twenty pounds each are placed inside of the shell with the crushed stone and when the shell revolves the balls run around inside and grind up the stone. After being ground for the required number of revolutions the stone dust is removed from the mill and 500 grams is weighed out and mixed with 90 cubic centimeters of water. This mixing is done by hand and should be kept up for five minutes. It is then placed in an airtight jar (an ordinary fruit jar) and allowed to stand for twenty four hours, when it is moulded into briquettes.

The machine for moulding the briquettes is shown in Fig. 2 The material is placed in the steel die "a" and pressure is applied by turning

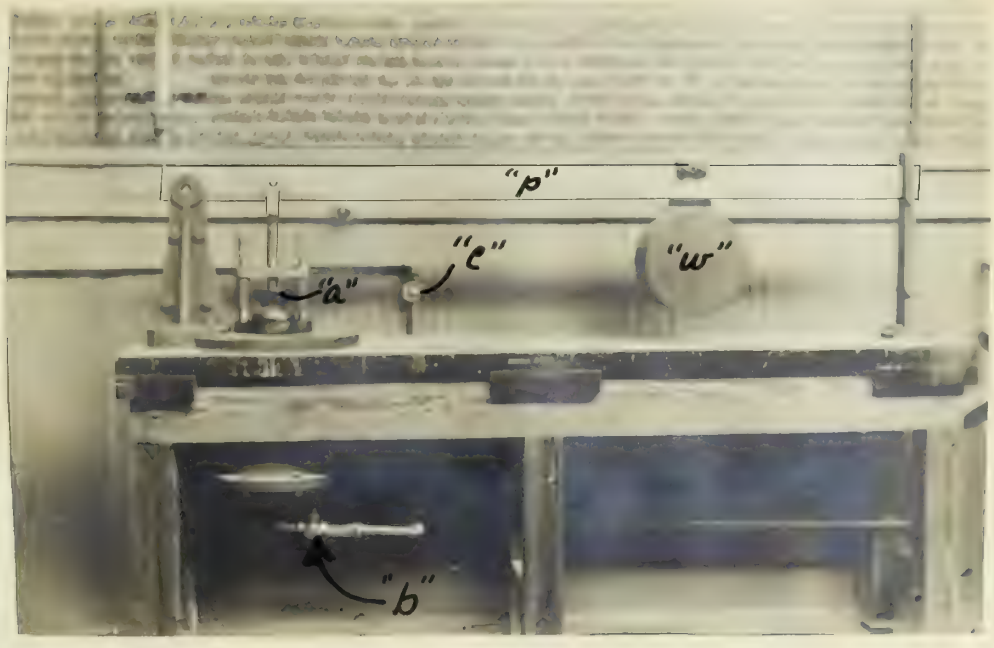


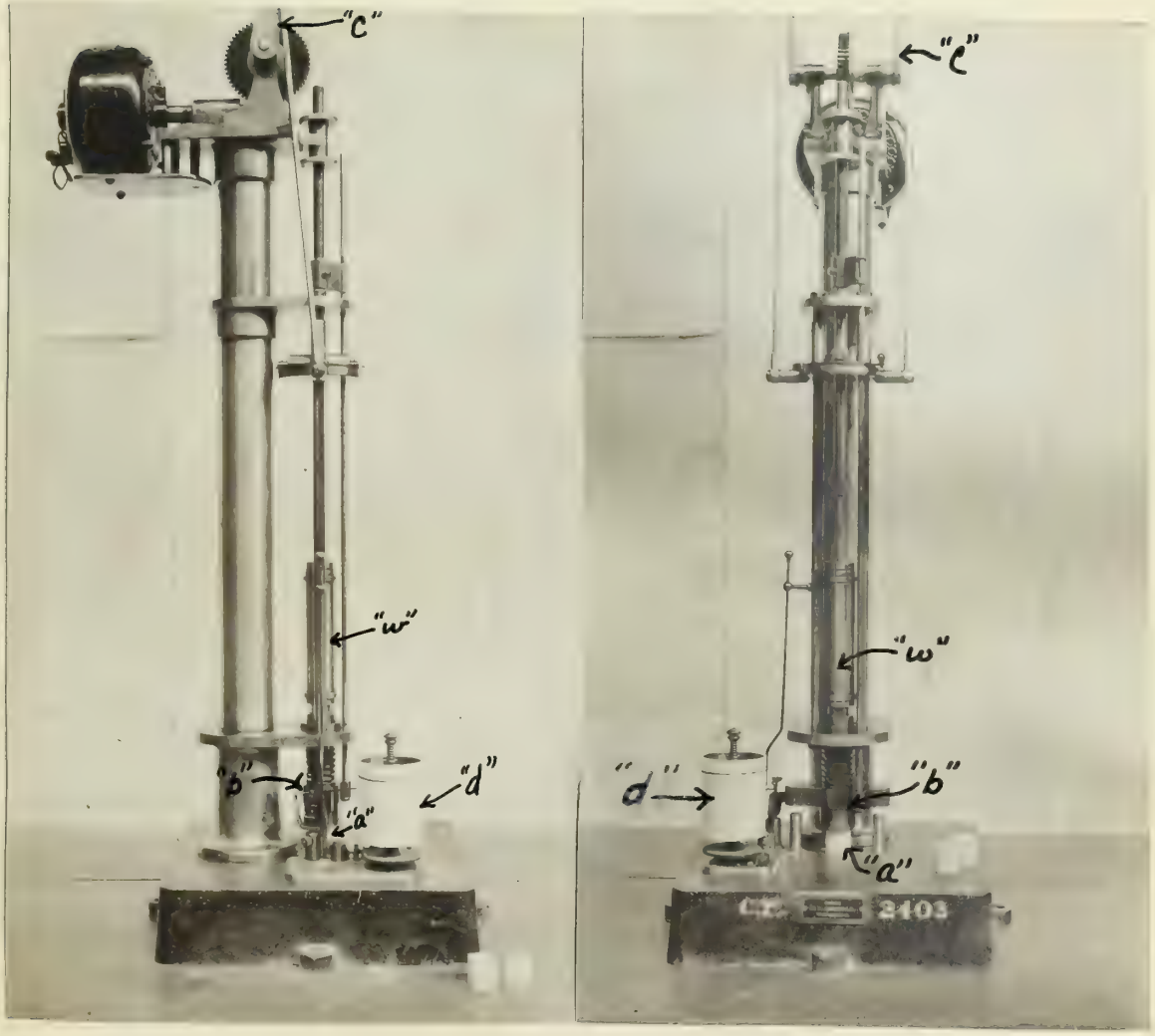
Fig. 2

Fig. 1

valve "b". The required pressure is regulated by means of wright "w" which can be moved along the lever arm "p". The time for the application of the pressure should be one minute. This can be regulated by throtteling the valve "c"

After the briquettes are made they are allowed to stand in a dry place for twelve hours, after the time of moulding, then they are placed in an oven having a temperature of 100° centigrade, where they remain for seven hours. After removal from the oven they are immediately placed in a desicator to cool. The briquettes usually remain in the desicator for about twenty minutes. They are then broken in the impact machine shown in Fig 3. The briquette is placed in position "a" under the movable part "b" which weighs one kilogram and rests upon the briquette. The hammer "w" is so arranged in the guides that with every revolution of the crank "c" it is lifted one centimeter and allowed to fall striking the head "b" which in turn reacts upon the briquette. These blows are repeated until failure occurred and are recorded upon the sheet of paper held on the recording drum "d". The points of initial failure and final breaking point are noted and a record of each is kept. It was thought that perhaps the point of initial failure might be of some value and so a record of it was kept.

The action of water under the steam roller in building roads in aiding the formation of the bond is well known to engineers, and in macadam



Side View

Front View

Fig. 3

construction the roadway is liberally sprinkled while final consolidation is going on. So it became apparent that a system of wet grinding would develop much higher cementing values than could be obtained by grinding the sample dry and subsequently mixing with a given amount of water. With very few exceptions higher cementing values are obtained due to the increased kneading action and more thorough decomposition.

The method of making the wet-grind test is as follows:— Five hundred grams of the crushed stone is placed in the ballmill with ninety cubic centimeters of water and revolved five thousand times. The material is then removed from the mill and immediately moulded into briquettes which are left to dry in air for twelve hours. The remainder of the process being the same as for the dry grind test.

DESCRIPTION OF TESTS

The dry grind test which was assumed as the standard for the tests made and described in the following pages differed slightly from the foregoing description. The wet material was allowed to stand in the jars for twelve hours instead of twenty four hours, to shorten the duration of the tests. After the briquettes were moulded they were placed in the order shown in fig 4 upon a 7 ± 13 centimetre paper which lies upon a zinc sheet of the same size and were always broken in the order made.

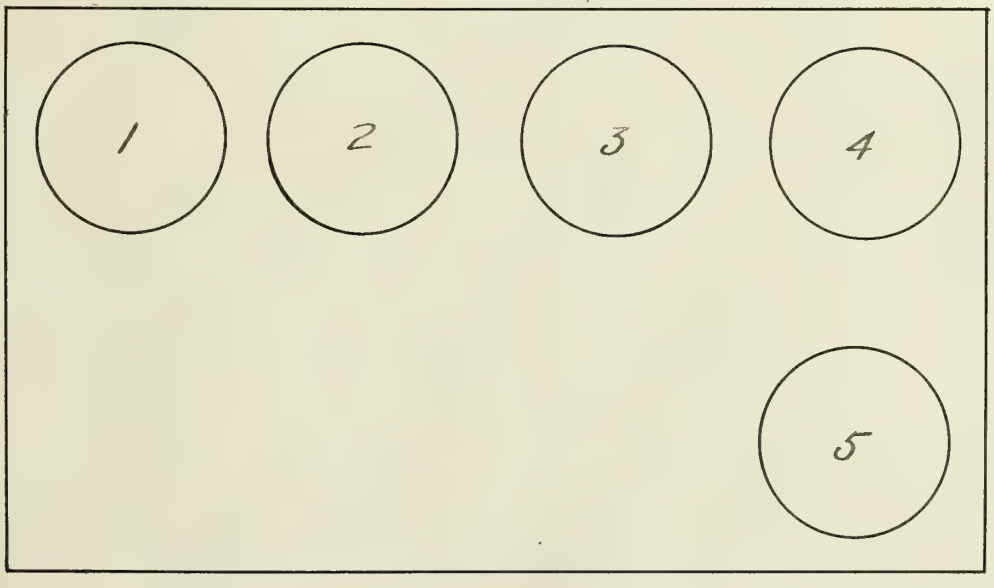


Fig 4

The assumed standard for the wet grind tests was the same as stated before except the time which the briquettes are allowed to stand in the air was seventeen instead of twenty four hours. This change was made so that the operations could be carried on at convenient periods.

The variations which were investigated

are stated below and will be discussed in the following pages in that order. In each case the variation was made from the assumed standard both for the wet and the dry ground material

Dry Ground Material

1. Variation of the time wet material is in the jar.
2. " " " " of applying pressure.
3. " " amount of water used in moulding.
4. " " the moulding pressure.
5. " " " time briquettes are in the oven.
6. " " " " of kneading.
7. " " " number of revolutions of the ball mill.

Wet Ground Material

1. Variation of the time briquettes are left in the air.
2. " " " " of applying pressure.
3. " " " amount of water.
4. " " " moulding pressure.
5. " " " temperature of the oven.

In order to make a fair comparison as to the effect of the different variations, three stones were selected upon which to preform all of the experiments. Owing to the limited time at the disposal of the writer only one of these stones was used in the following tests, this was a limestone from the Hawthorn quarry of Dolese and Shepard Co. The abrasion test, the toughness test, and the determination of the specific gravity and the absorption properties were determined for this stone and were as follows; —

Abrasion, per cent of wear.	3.95
Coefficient of hardness.	10.10
Toughness test.	11 blows
Weight per cubic foot.	171.45 pounds
Specific Gravity.	2.75
Absorption test.	1.13 pounds per cubic foot

RESULTS OF THE TESTS

Dry Ground Material

1. Variations of the Time in Jar.— The first variation from the standard was of the time which the wet material is allowed to stand in the closed jar before moulding. Five sets, five briquettes in each set, were made varying the time in jars from six hours to 12 days. The average results of each of these sets are given in Table I and also on Plate I, in the rear of the volume, by a curve having the hours in the jar as abscissas and final breaking points as ordinates.

Table I

Results of Variation in Time Material Left in Jar

Sample No	Time in Jar	Avg Point of Failure	
		Initial	Final
2	6 hrs	35	60
1	9 "	53	75
2	12 "	80	103
5	24 "	91	119
16	36 "	72	95
17	12 days	75	102

These results seem to show that there is a limit somewhere between twenty four and thirty six hours where the action of the water reaches a maximum and after that there is very little difference in the cementing value as shown by the thirty six hour and the twelve day tests.

2. Variation of Time of Applying Pressure in Moulding.— (a) The length of time which is consumed in the application of the pressure in moulding should have some effect upon the strength of the briquettes.

In testing for this variation four sets of briquettes were made varying the time of applying the pressure from 1/4 to 2 minutes. This was accomplished by throttling the valve "C" (See fig 2) so that pressure came on either fast or slow as desired. The results are given in Table 2 and a curve is shown by the black line on Plate 2 which shows average breaking loads as ordinates and times of applying pressure as abscissas.

The results show that after the briquette is once compressed so that it is hard in the center the variation is very slight for increased time of applying pressure, although results show a constant increase.

(6) A better showing of this variation was thought to be by variation of time of applying the pressure in a different manner. Instead of throttling the valve "C" (fig 2) to give the required time, it was opened wide so that the total pressure was applied in 15 seconds. As soon as the bar began to rise valve "b" was thrown into its middle position thus holding the pressure constant. The valve was kept in this position until the required time had elapsed when the pressure was released by

Table II

Results of Variation in Time in Applying Pressure

Sample No	Time of Applying Pressure Minutes	Average Point of Failure (a)		(b)	
		Initial	Final	Initial	Final
	1/4	4	14		
7	1/2	74	95		
6	1	80	103		
9	2	91	127		
22	1/2			49	61
23	1			59	81
21	2			97	126

opening valve "b". Three sets of briquettes were made in this manner and the results showed practically the same results as by the first method, only in a more pronounced manner owing to the more complete compression of the material in the briquette. The results of this variation are shown in Table II and by a curve on Plate 2.

3. Variation of Amount of Water Used in Moulding.— The amount of water which is used per unit weight of material should effect the strength of the briquettes. Six sets of briquettes were made varying the amounts of water used from 60 cubic centimeters of water per 500 grams of stone dust to 110 cubic centimeters of water per 500 grams of stone dust. The results are shown in Table III and by a curve in black ink on Plate 3, which shows average breaking loads as ordinates and the cubic centimeters of water as abscissas.

Table III

Results of Variation of Amount of Water

Sample No	C.C. Water	Average Point of Failure	
		Initial	Final
15	60	15	28
14	70	20	28
11	80	87	106
23	90	46	80
12	100	56	79
10	110	40	60

These results show that the amount of water present effects the cementing value by increasing the decomposition of the material thus tending

to increase the cementing value, at the same time however this water is present when the moulding is going on and tends to decrease the cementing value for, although some of the water is pressed out when the pressure is applied not all of it is pressed out; so that when the briquettes are dried out in the oven they are left more or less porous. It is evident that there must be some certain amount of water, varying of course with the different stone dusts, which will give a maximum cementing value for that stone dust. For the limestone tested, the maximum cementing value was reached with 80 cubic centimeters of water.

4. Variation of the Moulding Pressure.—

A variation of the intensity of the moulding pressure should show a difference in the results of the cementation tests. Four sets of briquettes were made varying the pressure from 68.9 to 124.8 kilograms per square centimeter. The results are shown in Table IV and by the black line curve on Plate 4 which shows the average breaking points as ordinates and the pressures in kilograms per square centimeters as abscissas.

Table IV

Results of Variation of Moulding Pressure

Sample No	Pressure		Average Point of Failure	
	Position of weight	K/□cm.	Initial	Final
20	10	68.9	38	55
18	15	87.7	48	65
17	20	106.3	56	75
19	25	124.8	67	88

The results do not show such a wide variation as might be expected, indicating that the length of time consumed in applying the pressure is of more importance than the amount of the pressure as will be seen by a comparison of the curves on Plate 4. with those on Plate 2

5 Variation of Time in Oven.—

In order to find out if the length of time which the briquettes are allowed to remain in the oven effects the cementing value, two sets were made, one in the standard way and the other set was allowed to remain in the oven for 60 hours. The results given in table V. show

Table V

Results of Variation of Time Briquettes are in Oven

Sample No	Time in Oven	Time in Air	Failure	
			Initial	Final
33	00 Hr.	19 Hr.	47	129
24	12 "	12 "	57	78
25	60 "	12 "	57	79

that the two sets referred to were exactly alike and a third set which was not placed in the oven at all gave very erratic results, having a very low point of initial failure and a high breaking point. All of the briquettes of the first set started to fail with the first few blows especially briquettes #1, 4 + 5 (See p. 6) which were the dryer. No 2 + 3 had very high breaking points and brought up the average. These results show that after the briquettes become thoroughly dry all additional time which they remained in the oven had no effect upon their cementing value.

6 Variation of Time of Kneading Material.—

By a more thorough mixing of the material with the water the decomposition of the particles mentioned on page 2 is materially aided and should give higher cementing values. Four sets of briquettes were made to determine the effect of a variation from 2½ minutes to 15 minutes in the time of kneading. The results are shown in Table VI and a curve on Plate 5 has the average breaking points as ordinates and times of kneading as abscissas

Table VI

Results of Variation of Time of Kneading

Sample No	Time of Kneeding Minutes	Avg Point of Failure	
		Initial	Final
30	2½	31	44
23	5	56	75
26a	10	71	103
26b	10	82	103
27	15	70	101

The results show that the greatest change in cementing values occurs between 2 and 10 minute points and that after 10 minutes of kneading there is no effect from more kneading.

7. Variations of the Number of Revolutions of the Ball Mill.—

Two grinds were made to determine if the number of revolutions of the ball mill over four thousand, would make any difference in the cementing value of the stone dust. One grind was run 5000 revolutions and the other 10000 revolutions. The results of these tests showed that there was no difference in the cementing values. A fineness test was also made showing that the additional 5000 did not increase the fineness of the material at all.

Wet Ground Material

With the system of wet grinding described in detail on page 7, a much higher cementing value was developed due to the increased kneading action and the more thorough decomposition of the particles by the action of the water.

One of the greatest difficulties met with in the wet grinds was the forming of balls of dough in the ball mill. These balls rolled around in the ballmill following the steel ballsand gathering around themselves more material just as a snow ball does when rolled through wet snow. When these balls form the material in them is not ground up and the small amount of material which is left is ground more than its share. There is no way to prevent this action and so the results obtained from the material is more or less unreliable.

1. Variation of Time Briquettes are Left in the Air.—

The action of the water on the material goes on after the briquettes are moulded and so there should be some difference in the strength of the briquettes if they are allowed to stand for a longer time in the air before placing them in the oven.

The results in table VII show that the variation is not very large still it is quite appreciable. Curve on Plate 6.

Table VII

Results of Variation of Time Briquettes are in Air

Sample No	Time in Air Hours	Avg Point of Failure	
		Initial	Final
49	88	191	257
41	36	146	209
63	17	134	193

2. Variation of Time of Applying Pressure.—

It was found by the dry grind tests that the length of time which is consumed in the application of the pressure in moulding had a marked effect upon the strength of the briquettes. Four sets of briquettes were made varying the time of applying the pressure in moulding from ½ minute to 2 minutes. The results are shown in table VIII. A curve on Plate 2 shows average breaking points as ordinates and time consumed as abcissas.

Table VIII

Results of Variation of Time of Applying Pressure

Sample No	Time Consumed Minutes	Initial	Final
47	½	64	102
41	1	134	193
48	2	221	268

These results show that the briquette is more solidly compressed with a longer time of application. The differences in the strength are even more marked than in the dry grinds.

3. Variation of the Amount of Water.—

The variation of the quantity of water used in the wet grinds should have a similar effect to that shown by the variation of the amount of water used in the dry grinds. Six sets of briquettes were made varying the amount of water from 60 cubic centimetres to 120 cubic centimetres per 500 grams of material. The results are shown in Table IX and by the blue curve on Plate 3.

Table IX

Results of Variation of Amount of Water

Sample No	C.C. Water	Average Point of Failure	
		Initial	Final
60	70	201	244
40	80	196	241
41	90	120	170
37	100	94	136
38	110	136	187
39	120	87	107

It is seen by a comparison of the two curves on Plate 3 that the amount of water used effects both the wet grinds & the dry grinds in a similar manner.

4 Variation of Pressure of Moulding. —

Four sets of briquettes were made to show the effect of variation of intensity of pressure in moulding. The results are shown in table X. and by the blue curves on plate 4. A comparison of the two curves on this plate shows that the variation of the pressures in both the dry and the

Table X

Results of Variation of Pressure in Moulding

Sample No	Pressure		Average Point of Failure	
	Arm	K/□cm	Initial	Final
44	10	68.9	112	164
43	15	87.7	134	193
41	20	106.3	181	210
42	25	124.8	180	221

wet grinds give similar results.

The results show that the briquettes are very

well compressed with the standard pressure of 106.3 kilograms per square centimetres and additional pressure does not increase the strength of the briquettes to a very great extent proportionately.

5. Variation of Temperature of the Oven.—

Two sets of briquettes were made at the same time and placed in two different ovens at different temperatures and left there the same length of time, after which they were broken. The results are shown in Table XI.

Table XI

Results of Variation of Temperature of Oven

Sample No	Degrees Centigrade Temperature	Average Point of Failure	
		Initial	Final
50	67°	216	247
51	110°	221	249

The length of time which the briquettes are left in the oven had no effect upon the cementing values as shown on page 14 neither did the temperature of the oven have any effect. After the briquettes become thoroughly dry, all additional intensity of heat, below a dehydrating temperature has no effect upon their strength.

CONCLUSION

The greatest variation found in both the wet and the dry grinds are in those tests in which the action of the water has either been increased or decreased. In the dry grinds, the time which the wet material is allowed to stand in the jars, the amount of water used in kneading the material, and the length of time used in kneading have the greatest effect upon the strength of the briquettes. In the wet grinds the amount of water used in the ball mill and the time briquettes are left in air have the greatest effect.

The effect of actually increasing the amount of water in aiding the decomposition of the material seemes to be overbalanced by the effect of the pressure of the water in the moulding which does not allow a compact briquette and so it is found that when the amount of water is increased above the standard, in both the wet and the dry grinds, the result is a weaker briquette. The time which the dry grind material is allowed to stand in the jars and the time of kneading enter directly into the results by aiding the action of the water present. The same is true for the wet grind variations.

The results of the tests upon this stone would suggest a better standard than the one assumed so that any slight variation from it would not effect the cementing value so much. The specifications for a new standard test for this stone is as follows:—

Dry Ground Material

1. Amount of water 80 cubic centimetres per 500 grams.
2. Time of kneeding 10 minutes.
3. " " jar 24 hours.
4. " " applying pressure 2 minutes.
5. Amount of pressure 106.3 kilograms per sq. C.
6. Time of briquettes in air 12 hours.
7. " " " " oven 7 "

Wet-Ground Material

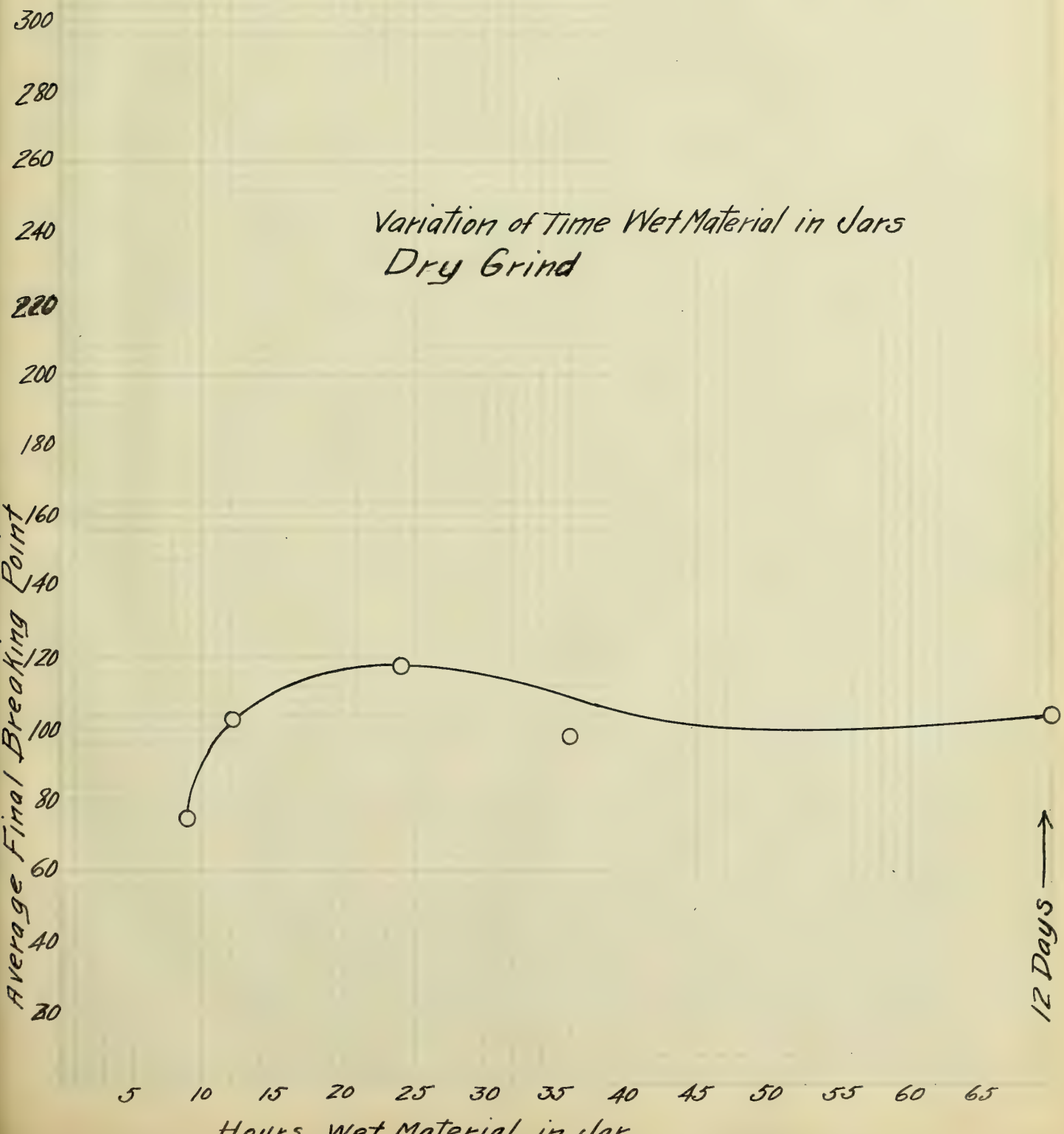
1. Amount of water 71 c.c per 500 g. material.
2. Time of applying pressure 2 minutes.
3. Amount of pressure 106 kilos per square centimetre.
4. Time of briquettes in air 24 hours.
5. " " " " oven 7 "

The greatest source of error in the dry grinds occured when the material was allowed to stand with the jars erect so that the lower part of the material became wetter than the part above. This was partly overcome by laying the jars on their sides so the material had less depth and more horizontal area. When the material was taken out it was found to be a much more uniform mixture than by the old method. Aside from this small source of error the dry ground material is always the same and can be depended upon to give uniform results.

In the wet grinds the trouble experienced by the formation of balls of dough together with the unreliable grinding cause variable results on account of the lack of uniformity of the material. This variability of the wet grinds is shown by the wide differences in the values of separate

briquettes of the same set. Judging from the results of the tests, the dry-grinds give more uniform and more reliable results than do the wet-grinds.

Plate I.


Variation of Time Wet Material in Jars
Dry Grind
Average Final Breaking Point
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
12 Days
5
10
15
20
25
30
35
40
45
50
55
60
65
Hours Wet Material in Jar

Variation of Time in Applying Pressure

Black Line — Dry Grinds (a)

Blue Line — Wet Grinds

Dotted Line-- Dry Grinds (b)

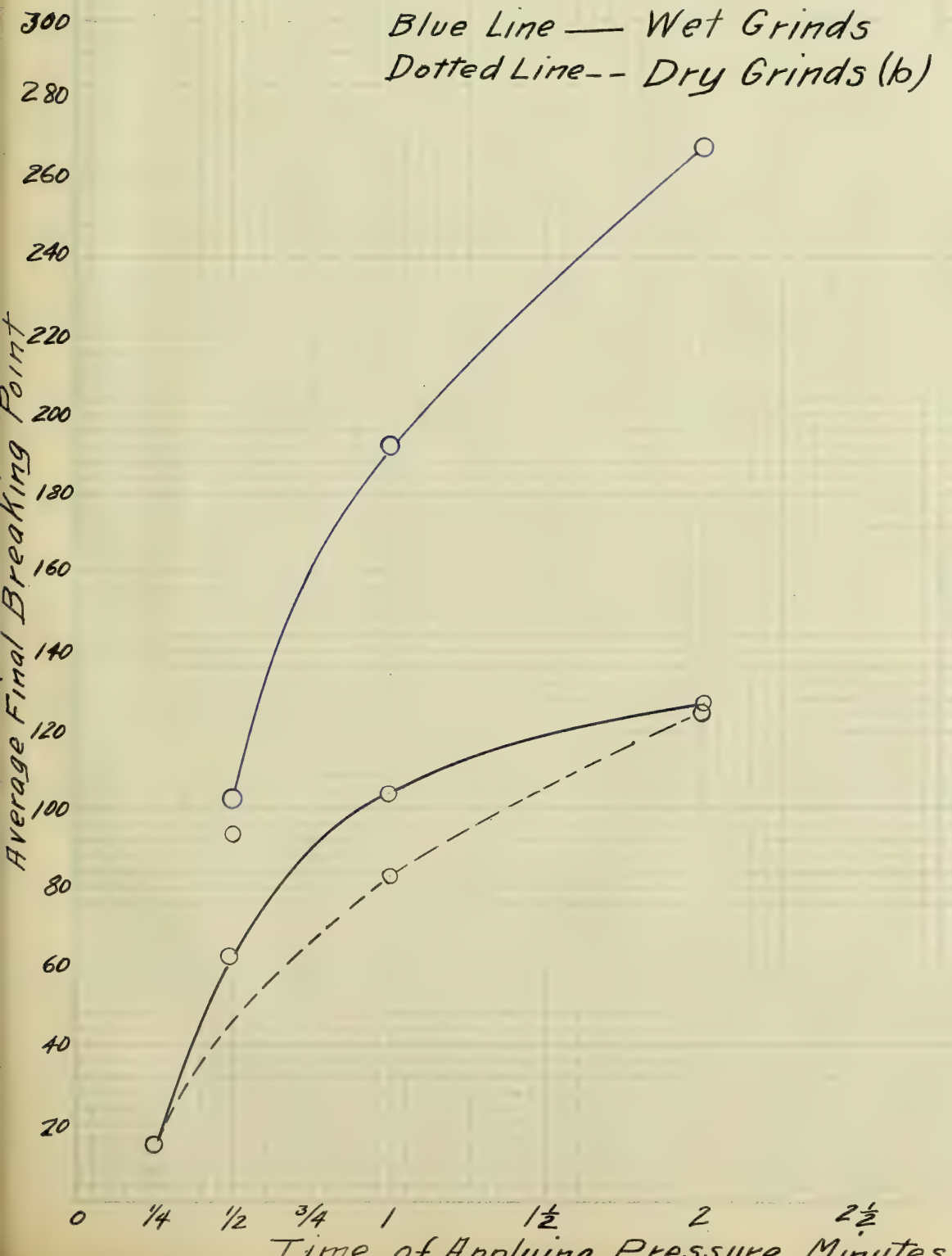


Plate 4

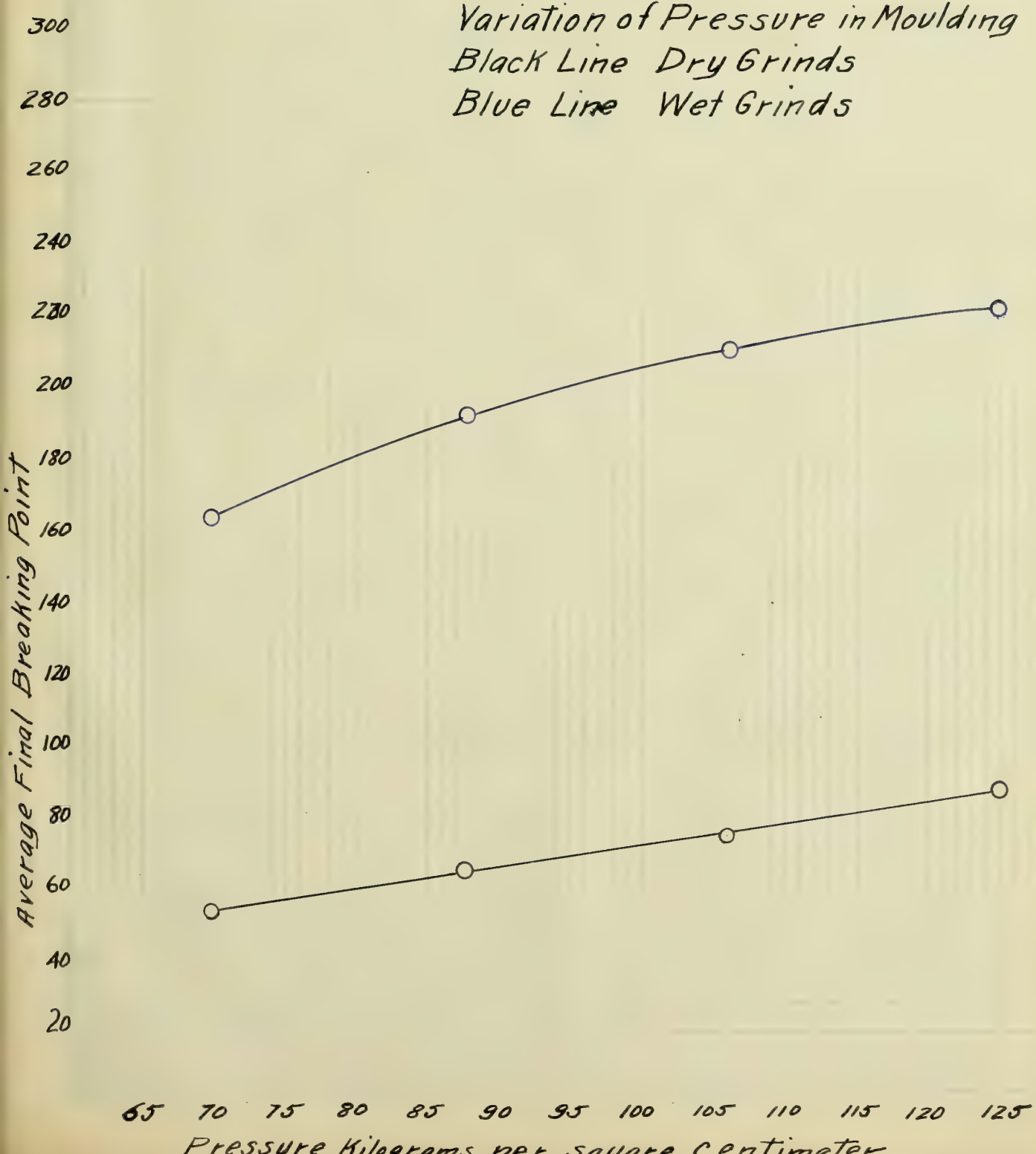
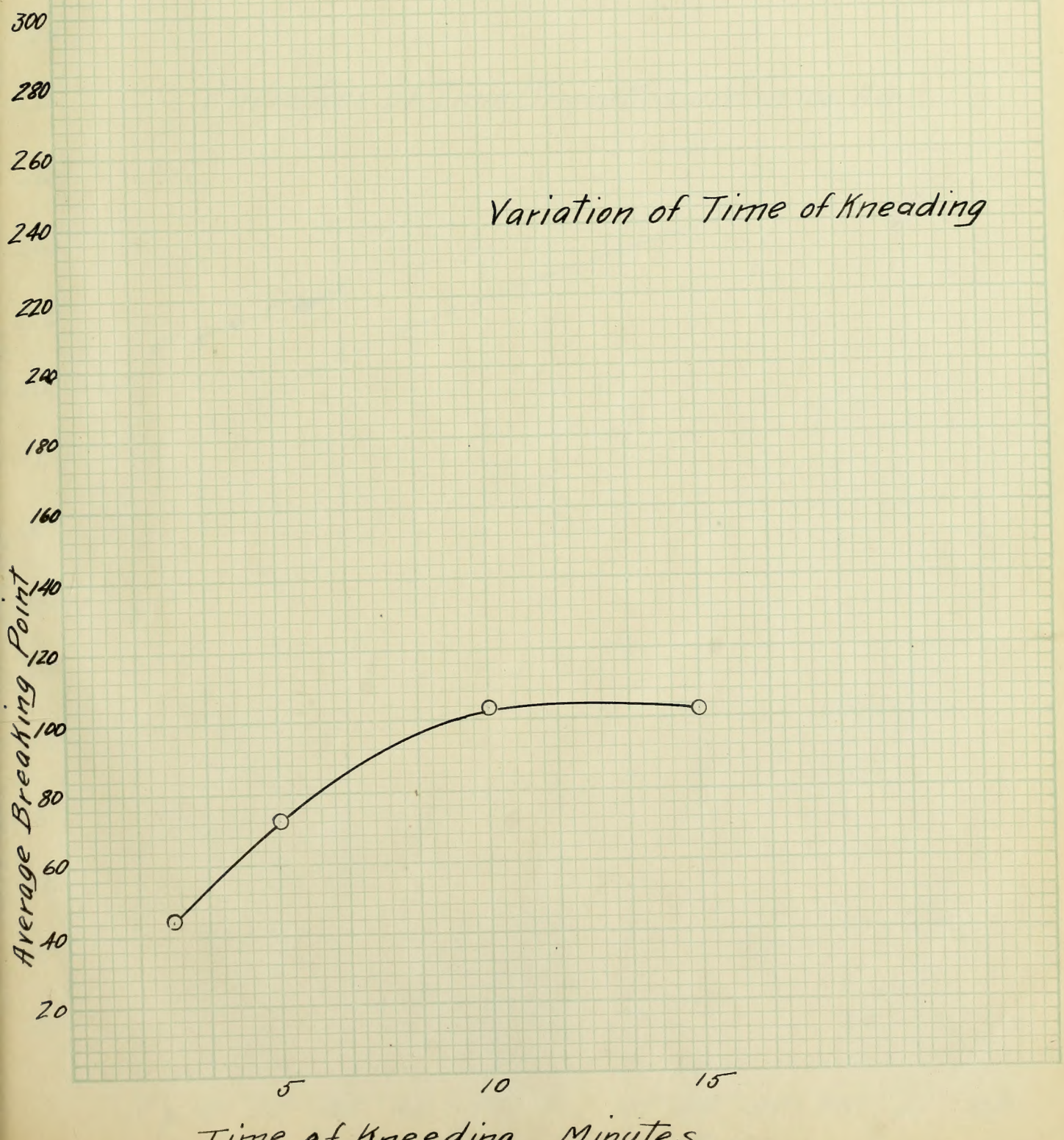

Variation of Pressure in Moulding
Black Line Dry Grinds
Blue Line Wet Grinds
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Average Final Breaking Point
65 70 75 80 85 90 95 100 105 110 115 120 125
Pressure Kilograms per square centimeter

Plate 5


Variation of Time of Kneading
300
280
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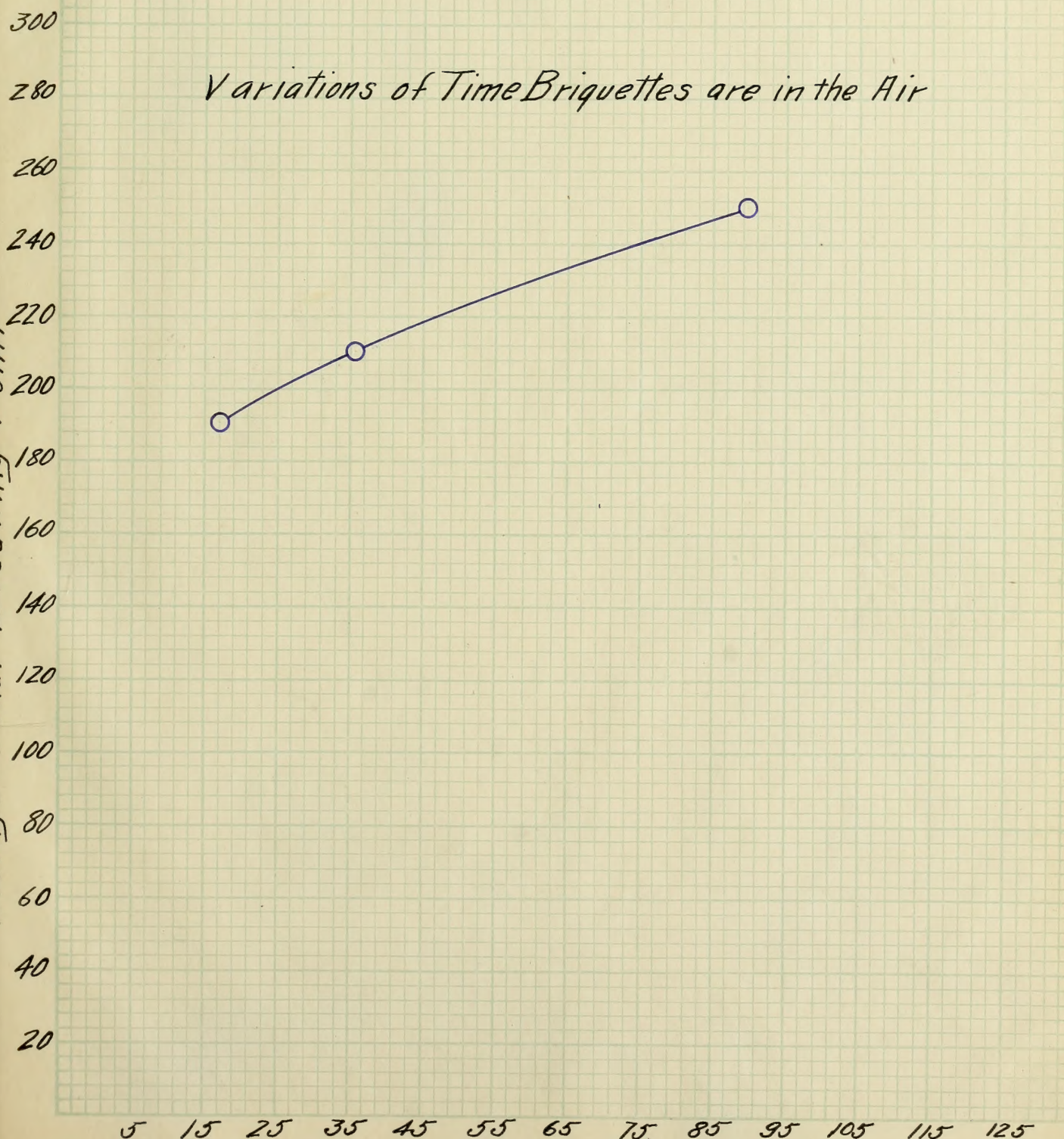
80
60
40
20
Average Breaking Point
5
10
15
Time of Kneeding Minutes

Plate 6


Variations of Time Briquettes are in the Air
Average Final Breaking Point
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
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35
45
55
65
75
85
95
105
115
125
Hours Briquettes in Air

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